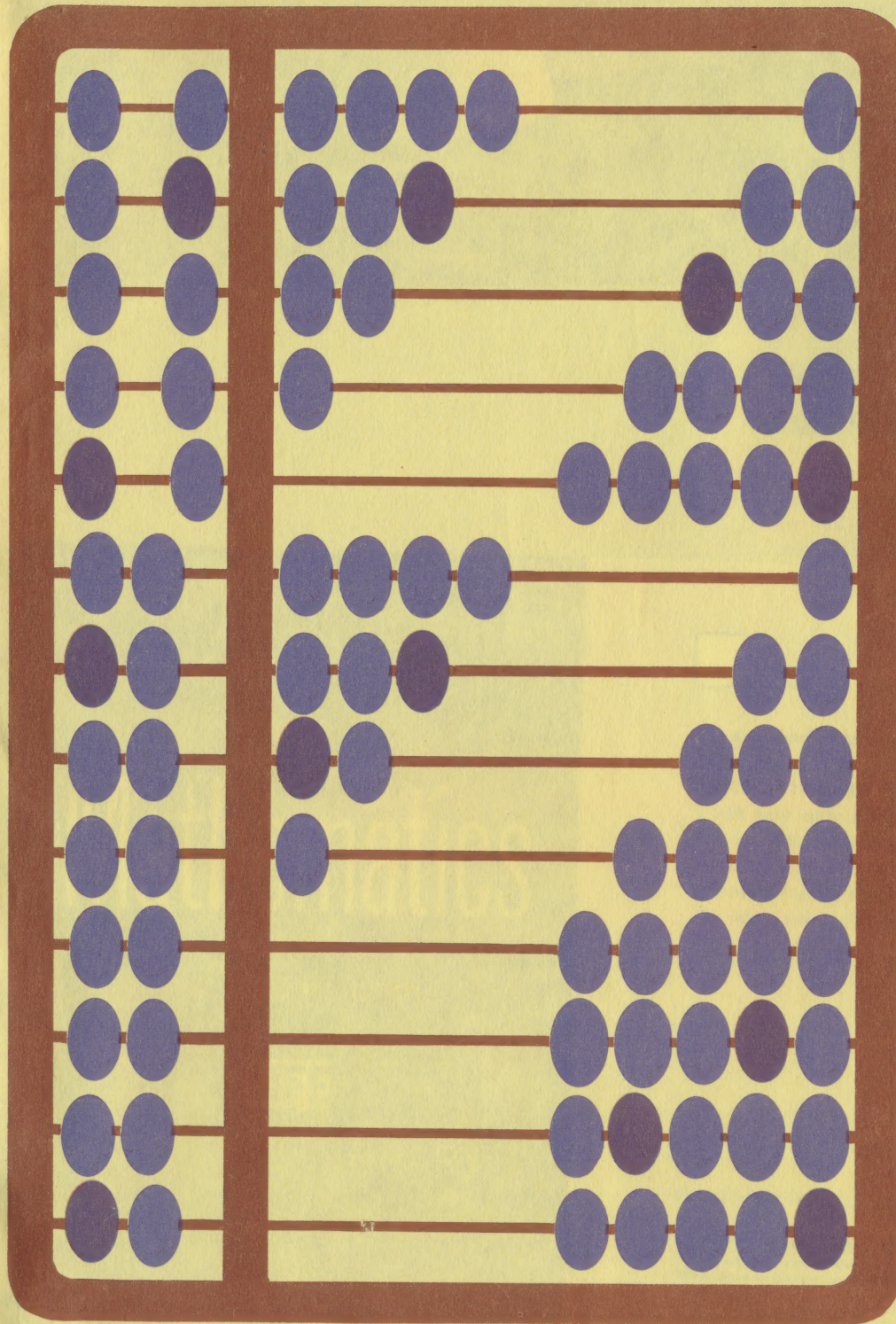




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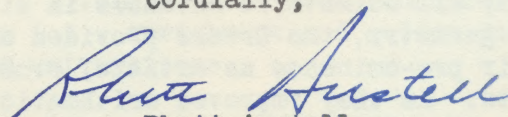
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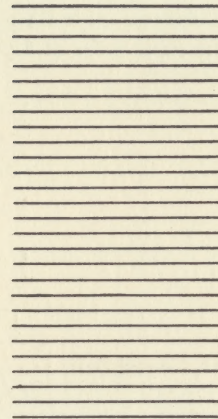
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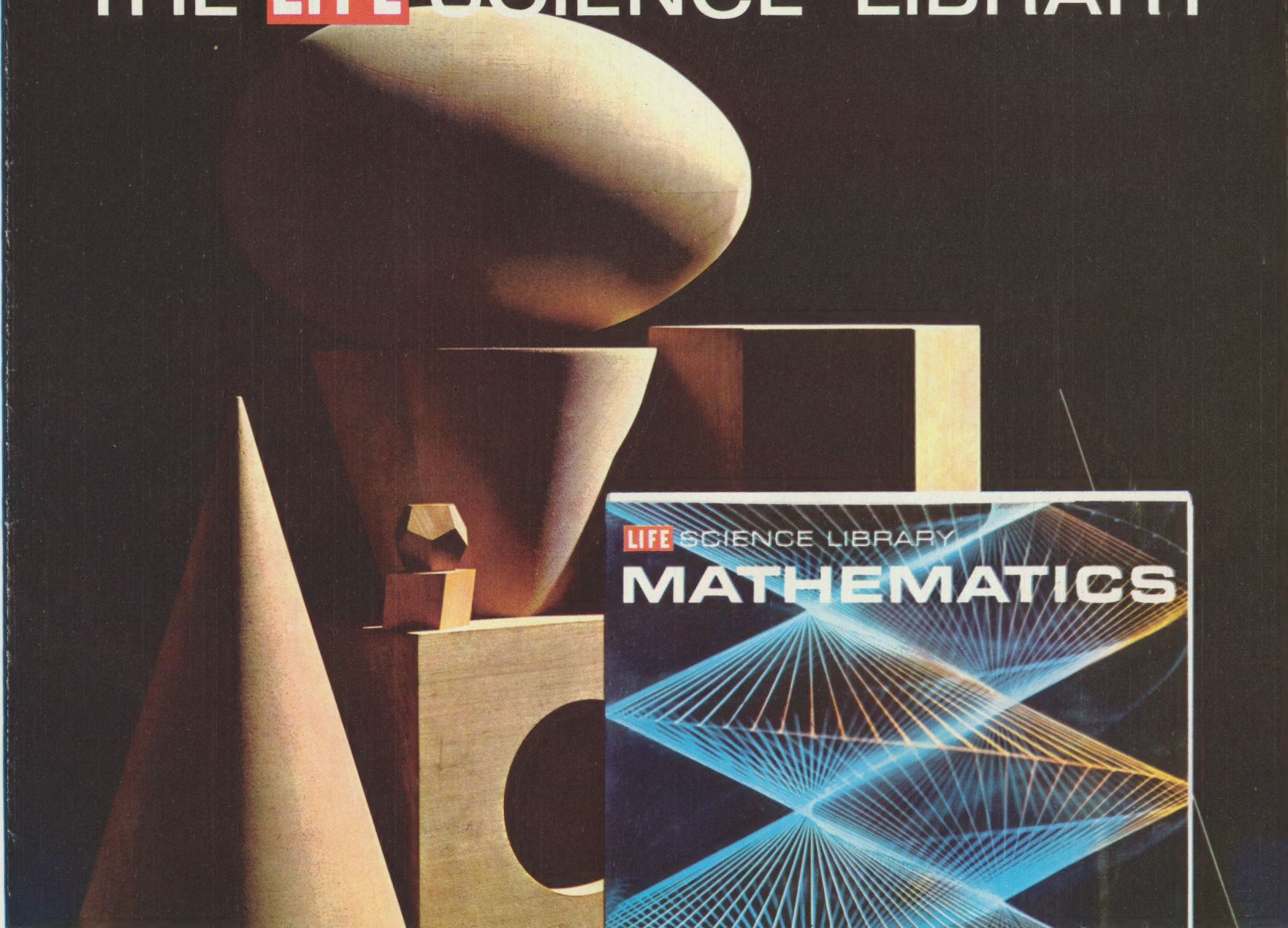
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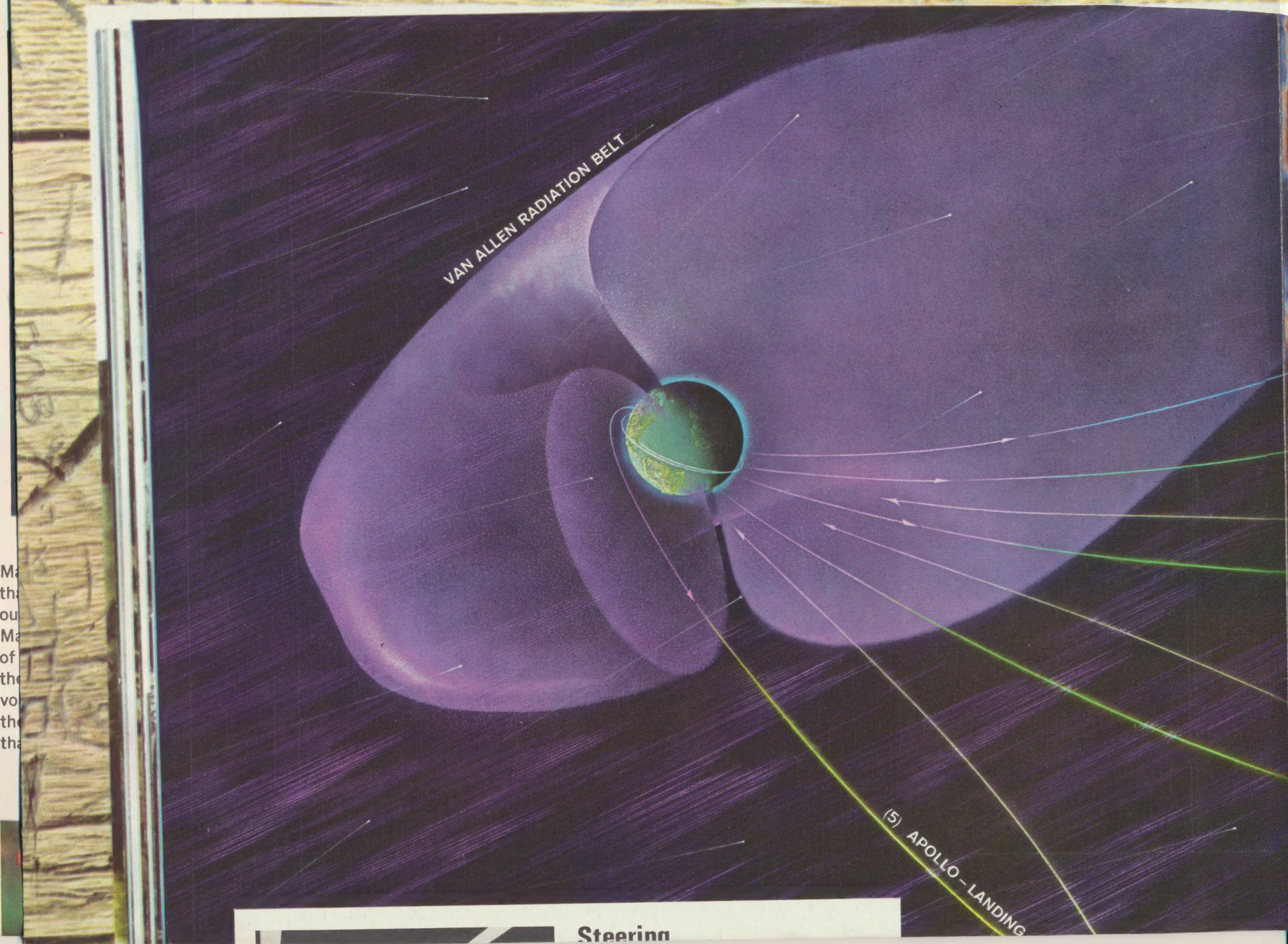
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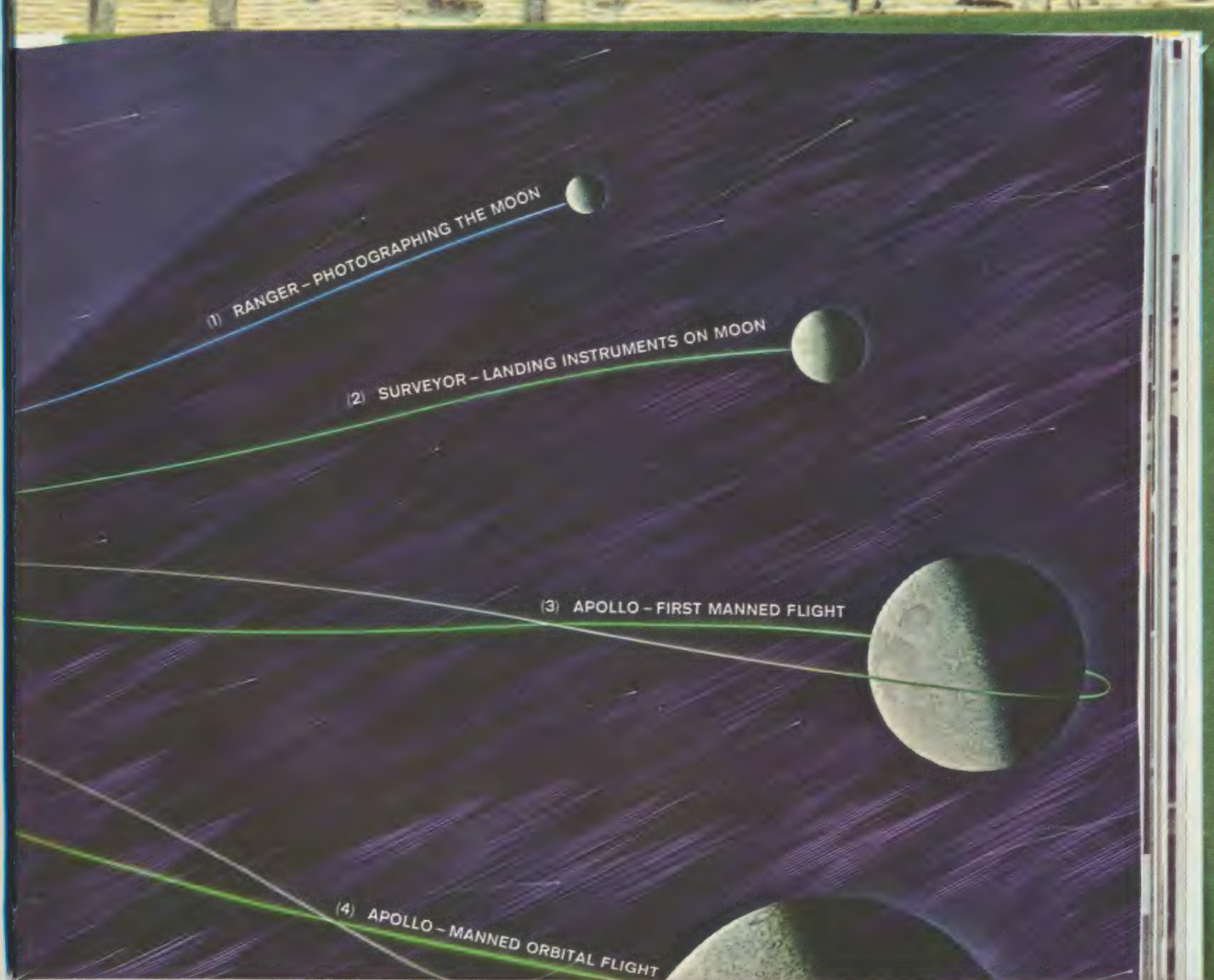


(1) RANGER - PHOTOGRAPHING THE MOON

(2) SURVEYOR - LANDING INSTRUMENTS ON MOON

(3) APOLLO - FIRST MANNED FLIGHT

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**MATHEMATICS** measures 8½ x 11 inches (the two-page spread shown here is actual size). It contains 200 pages, with hundreds of paintings, photographs, charts, diagrams and line drawings. There are 35,000 words of authoritative text, 72 pages of full color. Complete index.

the basic techniques of algebra and geometry. One found in school curricula. Emphasis was on the exciting history of mathematics, the variety of its forms; on understanding what mathematics is created.

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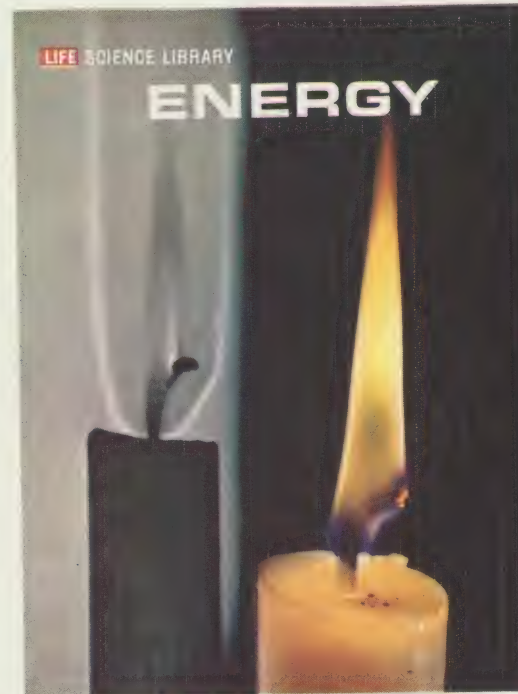
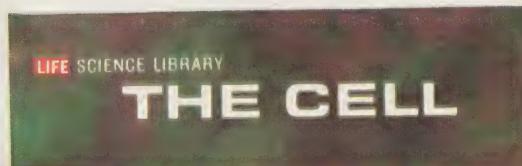


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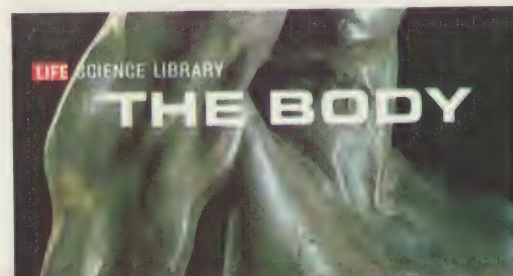
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Matter is the basic stuff of the universe. It is fuel that powers rockets; liquid so cold that it climbs out of a glass; coal that turns into diamonds. Matter is metal from the earth and the sea, alloys of metal that have changed history, and today, the atomic bomb and the hydrogen bomb. This volume presents the nature, the properties, and the evolution of matter in word-and-picture terms that you will read and absorb with eagerness.



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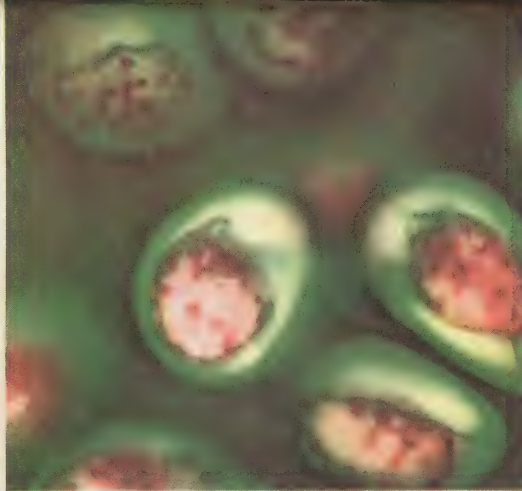


### MACHINES

Anything with moving parts is a machine, from a lever to a locomotive. The first machines were simple ways to make work easier. The proliferation of machines brought on the Industrial Revolution. Today, machines govern business and the kitchen, war and travel: they pervade our lives. LIFE's book traces the machine from the discovery of fire to the harnessing of nuclear power, from the invention of the wheel to the building of rockets to the moon.







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You can hold the brain, center of your intelligence, in your hand. Understanding how it works is something else again. Only in recent years have we begun to discern the nature of instincts, how brain cells work, how the brain directs the body, the nature of memory and the ability to learn. LIFE's book explores what we know about our minds and their powers and examines the fundamental question: are we getting any smarter?

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# $\pi$



**WEAVING BY THE CARD**  
In 1726 a French engineer invented this automatic loom. An endless chain of punched cards was set to rotate past the needles of the loom. As the cards moved by, only the needles which matched holes were able to penetrate and their threads determined the pattern.

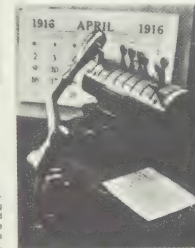
**PUNCHING BY MACHINE**  
By 1890 Herman Hollerith, an American engineer, had perfected the first data-processing machine to use punched cards. The holes had to be punched one by one, but by 1916 the device at right had been patented to solve this problem, punching nine holes in a card at once.

## The Wonderful Yes-or-No Language of Punched Cards

The punched card, emblem of the age of electronic computers, was invented nearly 250 years ago, when it was used in a loom (left) to speed the weaving of patterned fabrics. But the holed cards really came into their own in 1890 when they were used in a mechanical computer to handle U.S. census figures—at a saving of five million dollars.

Today the punched card is an indispensable tool of the electronic computer. Data are recorded on the cards by punching holes in specific locations. These holes can be "read" by computers in much the same way the loom follows its weaving pattern: the computer's electric current, like the loom's needle, either pierces the card at a given spot or does not, depending on whether there is a hole there.

Since the computer is limited to this pierce or no-pierce response, all numbers being fed into it must be punched into the cards in a code made up of holes or no-holes. All sorts of punched-card codes have been devised, including the basic binary code which operates on the binary number system explained on the opposite page. Binary numbers, made up of combinations of 1 and 0, are represented on the cards by holes and blanks.

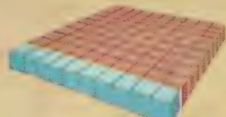


## THE DECIMAL SYSTEM OF COUNTING

The familiar decimal system of counting needs just 10 symbols—0 and the digits 1 through 9—to write any number, no matter how large. All the numbers in this convenient system are built up out of blocks valued at 1, 10 and powers of 10 (such as 100, which is 10 x 10; 1,000, which is 10 x 10 x 10; etc.). As is shown in the table under the row of blocks below, to build the number 3 requires three 1-blocks. To build the number 13, for the sign in the grocer's window at right, requires one block of 10 and three blocks of 1. Similarly, 49 needs four 10s and nine 1s; 125 needs one 100-block, two 10s and five 1s. Reading from left to right, every decimal number is a summary of the kinds of blocks it takes to build it up.



COUNTING BY POWERS OF 10

|                                                                                     |                                                                                     |                                                                                     |   |     |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---|-----|
|  |  |  |   |     |
| 100                                                                                 | 10                                                                                  | 1                                                                                   |   |     |
|                                                                                     |                                                                                     |                                                                                     | 1 | 3   |
|                                                                                     |                                                                                     |                                                                                     | 3 | 13  |
|                                                                                     |                                                                                     |                                                                                     | 9 | 49  |
|                                                                                     |                                                                                     |                                                                                     | 5 | 125 |
| 1                                                                                   |                                                                                     |                                                                                     | 2 |     |

COUNTING BY POWERS OF 2

|                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                     |                                                                                     |   |     |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---|-----|
|  |  |  |  |  |  |  |   |     |
| 64                                                                                  | 32                                                                                  | 16                                                                                  | 8                                                                                   | 4                                                                                   | 2                                                                                   | 1                                                                                   |   |     |
|                                                                                     |                                                                                     |                                                                                     | 1                                                                                   | 1                                                                                   | 0                                                                                   | 1                                                                                   | 1 | 13  |
|                                                                                     |                                                                                     |                                                                                     | 0                                                                                   | 0                                                                                   | 0                                                                                   | 0                                                                                   | 1 | 49  |
|                                                                                     |                                                                                     |                                                                                     | 1                                                                                   | 1                                                                                   | 0                                                                                   | 1                                                                                   | 1 | 125 |
| 1                                                                                   | 1                                                                                   | 1                                                                                   | 1                                                                                   | 1                                                                                   |                                                                                     |                                                                                     |   |     |

## THE BINARY SYSTEM OF COUNTING

The binary system uses blocks worth 1, 2 and powers of 2 (such as 4, which is 2 x 2; 8, which is 2 x 2 x 2; etc.). To build the number 3 from binary blocks requires one 1-block and one 2-block, so it is written 11. To build binary 13 for the grocer at the right requires one 8-block, one 4-block, no 2-blocks and one 1-block—written as 1101. The number 49 needs one 32, one 16, no 8, no 4, no 2 and one 1—written as 11001. In the same way, 125 is written as 1111101. In the yes-no language of electronic computers, when the binary system writes 100 as 1100100, it is really saying: "A block of 64, yes; a block of 32, yes; a block of 16, no; a block of 8, no; a block of 4, yes; a block of 2, no; a unit, no."



## CHAPTER I

Man's first experience with numbers was tied to his need to measure: to count the days, divide the seasons, plan the harvests. First he used "one" and "many," later a system of twenty numbers (from his fingers and toes) and even a system of sixty numbers, before arriving at the 10-basic Arabic system we use today. In Chapter I you learn how our number system developed, and how the most sophisticated problems are now being solved by the simplest counting system of all. You will understand why "a score" came into being, why we have 60 minutes in an hour, why the French express 80 as "four twenties." You will understand why mathematics is truly the universal language, and why it is the language scientists contemplate using when attempts are made to communicate with intelligent life on other planets.



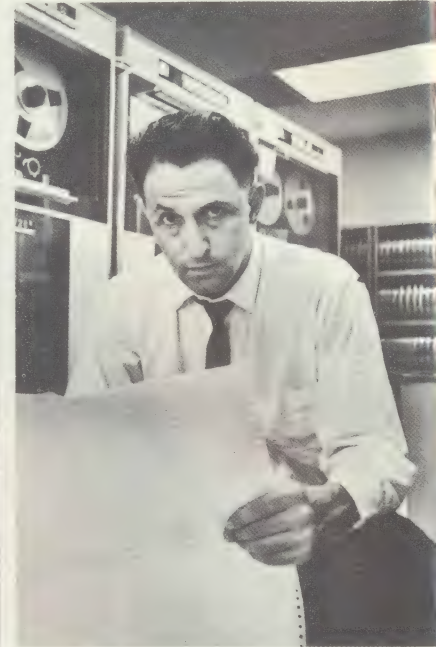
## Navigators Charting Courses to Outer Space

Aside from universities, the Department of Defense and the aircraft and electronics industries are the chief employers of mathematicians in the United States. One important field in which they work is celestial exploration: mathematicians—like the two shown here—must do the spadework for the space race. For a single space flight, they must compute about 100 trajectories, then choose the best one—plus another 20 or so alternatives for emergencies. Among the myriad factors they have to deal with are the possibilities of collision with meteorites, the safest routes through radiation, and the weight and

rate of expenditure of fuel. The actual figuring of each trajectory takes a computer a matter of seconds—but only after five people have worked four or five months to feed it the correct information. Not until the mathematicians are finished can the engineers proceed with the construction of spacecraft and launching of flights. The importance of mathematics was underscored in the first Mariner flight toward Venus. A minute typographical slip in one mathematical equation that was fed into a computer ruined the entire flight—the \$18.5 million Mariner went off course and had to be destroyed.

### A PERFECTOR OF QUESTIONS

Poring over figures in the computer laboratory (right) is the RAND Corporation's athletic Dr. Richard Bellman, who plays one of the most famous games of tennis in California. His mathematical specialty is dynamic programming, which sets up a computer so that it can keep finding answers as the problem it is working on changes. Typical examples are the minute-to-minute guidance of a satellite or day-to-day analysis of the fluctuating stock market. The difficulty, says Dr. Bellman, is in formulating a problem. "We often find," he says, "that a good question is more important than a good answer."



### THE "THREE-BODY" EXPERT

Examining a transparent celestial sphere is General Electric's cheerful specialist in space mechanics, Victor Szabohelyi (left), who enjoys predicting a phenomenon in the skies by deduction and letting someone else observe it in fact. "If he can't observe it," says Szabohelyi, "I don't admit that it doesn't exist. I say that he might not know how to observe." Recently he has been directing work on ways to slow

down a spaceship before a moon landing. But he calls his most important contribution his study of the "three-body problem": calculating how three celestial bodies—the earth, the moon and a spaceship, for example—constantly change position in relation to one another. No one formula has yet been found to cover all celestial trios, but Szabohelyi's techniques have proved immensely valuable in space exploration.

# 1+1=2

**CHAPTER II** Building on the pioneering brilliance of the Babylonian calculators, the ancient Greeks, through geometry, established the foundations of mathematics as it exists today—on the basis of logical proof. Their work was done amid drama and strife. Pythagoras and his mystical society of philosopher-mathematicians went from discovery to discovery until they foundered on their discovery of irrationals, which to them were disastrous flaws in the perfection of numbers. Zeno baited the Pythagoreans with his famous paradoxes. Euclid wrote his great **Elements** which became one of the best-selling books of all time. Then the slaying by the Romans of the great mathematician and applied engineer Archimedes postponed until the 20th Century "The Golden Age of Mathematics"—whose practitioners are portrayed by LIFE photographer Alfred Eisenstaedt.

y<sup>2</sup>



$\sqrt{3}$ 


#### EARLY CHRISTIAN STARGAZERS

This 13th Century French miniature, the frontispiece to a psalm book, shows three medieval monks practicing astronomical techniques newly introduced from Islam. The man in the center

sights a star along the bar of an astrolabe as an assistant at the right reads from astronomical tables, and a clerk (left) records the observations. They may have been working on a calendar.

### The Pervasive Influence of the Stars

From the earliest times, mathematicians have fastened their gaze on the heavens. Islamic astronomers of the Middle Ages—having learned from captured Greek texts how to build mathematical instruments—were setting up observatories and charting the movements of stars and planets while contemporary Europeans were ignorant of nearly all ancient science.

However, as mathematical knowledge

filtered into a Renaissance Europe in love with science but still married to superstition, a sharp division began to appear between the true science of astronomy and the pseudo science of astrology. "God did not create the planets and stars with the intention that they should dominate man," the great Swiss physician Paracelsus commented in 1541, "but that they, like other creatures, should obey and serve him."



#### MOSLEM MAP OF THE HEAVENS

This 13th Century astrolabe is engraved with a star map which can be rotated to find the position of stars on any night. On its opposite side is a movable bar used for sighting the angle that sun and stars make with the horizon, in order to determine latitude and the time of day.



#### ASTROLOGY WITHOUT STARS

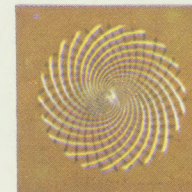
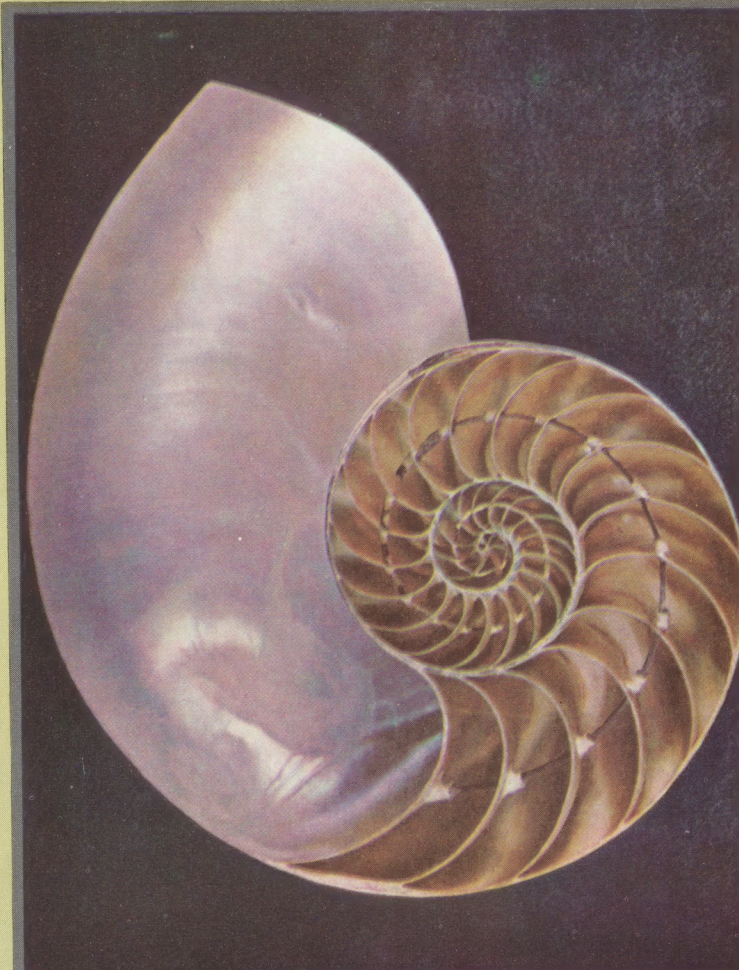
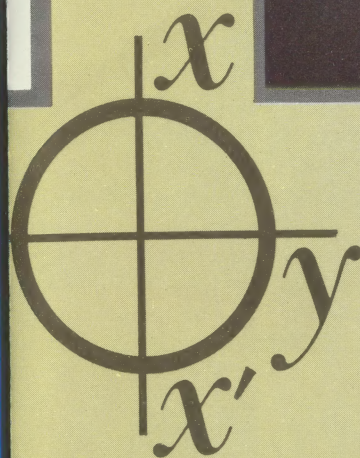
Using a geometric calculator like the one above, 13th Century Moslems could cast a horoscope based on chance rather than observation. Lots were drawn and the results, registered on the calculator dial, gave the planets arbitrary positions from which the horoscope could be cast.

#### FIGURING THE EARTH'S TILT

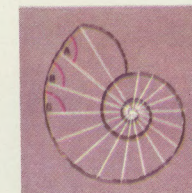
By aligning the top rings of an armillary sphere (left) with various celestial bodies, Moslem astronomers of the 16th Century could calculate the time of day or year, or measure the tilt of the earth's axis or the height of the sun. This instrument is an exact copy of an ancient Greek model.

**CHAPTER III** From the cryptic inscriptions of ancient Egypt and Babylonia emerges algebra—that potent method and symbolism that is the basic dialect of all modern mathematics. This chapter tracks mankind's painful struggle to find ways of breaking down algebraic equations: the trial and error of the pragmatic Babylonians and Egyptians, the pure theory of the Greek geometers, the patient research of the Hindu and Moslem scholars, and the intellectual wagering matches of the Renaissance's wily equation-solvers. Here you can follow man's tussle with the riddles of negative and imaginary numbers. Paintings, manuscripts and rare artifacts make vivid the major contributions of history's great civilizations to the steadily growing science of mathematics, while marginal diagrams illustrate principles discussed in the text.

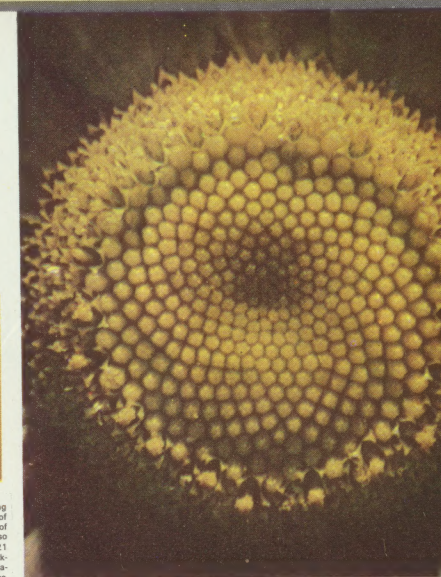




**A SPIRALED FLOWER**  
The diagram above reveals the double spiraling of the daisy head at right. Two opposite sets of rotating spirals are formed by the arrangement of the individual florets in the head. They are also near-perfect equiangular spirals. There are 21 in the clockwise direction and 34 counterclockwise. This 21:34 ratio is composed of two adjacent terms in the mysterious Fibonacci sequence.



**A SPIRALED SHELL**  
The cutaway of a chambered nautilus shell (opposite) shows its compartments. Only the outmost is the animal's home at any given time. Collectively, these chambers form an equiangular spiral (above); the black spiral intersects all of the white radii at exactly the same angle, so that the angles A, B, C and so on around the shell are always identical to one another.



### The Mysterious Mathematics of Nature's Spirals

Nature never has been content with simple shapes, but has created all kinds of intricate mathematical designs, including a variety of spirals. For example, the shell of the chambered nautilus (opposite) is an equiangular, or logarithmic, spiral; as can be seen in the diagram, the curve of the spiral always intersects the outreaching radii at a fixed angle. Logarithmic spirals also occur in the curve of elephants' tusks, the horns of wild sheep and even canaries' claws. Similar, though less precise, spirals are formed by the tiny florets in the core of daisy blossoms (above). The eye sees these spirals (diagram at upper left) as two distinct sets, radiating clockwise and counterclockwise, with each set always made up of a predetermined number of

spirals. Most daisies have 21 and 34. Similar arrangements of opposing spirals are found in pine-cone scales (5 one way, 8 the other), the humps on pineapples (8 and 13) and the leaves of many trees. This phenomenon is made all the more mysterious by its relationship with a certain mathematical sequence known by the nickname of its medieval discoverer, Leonardo ("Fibonacci") da Pisa. The Fibonacci sequence is produced by starting with 1 and adding the last two numbers to arrive at the next: 1, 1, 2, 3, 5, 8, 13, 21, 34, etc. The daisy's spiral ratio of 21:34 corresponds to two adjacent Fibonacci numbers, as do the pine cone's 5:8 and the pineapple's 8:13—and the same is true of many other plants with a spiral leaf-growth pattern.

**CHAPTER IV** In the 17th Century the versatile French soldier-mathematician Descartes discovered how to wed geometry and algebra so that every geometrical shape or curve could be expressed by an algebraic equation and vice versa. This union, called analytic geometry, paved the way to the use of mathematical methods in all branches of human knowledge and especially in the exact sciences. You recognize how your own street address holds the key to understanding Descartes' discovery. The double spirals in the flower above have a mysterious numerical relationship to each other which is echoed in the Golden Rectangle proportions of the Greek Parthenon and many great paintings. In a stunning series of pictures you see how many of the forms in nature along with beautiful works of art all embody simple mathematical concepts.



*leonem*," which, freely translated, means "I recognize the lion by his paw."

Logicians of the next generation sharply criticized both Newton and Leibniz for having used the equivalents of infinitesimals—for having added up nothings to create the somethings of areas, and for having shaved down rates of change to instantaneous slopes measured in no time at all. The Irish metaphysician Bishop Berkeley, in an essay entitled "The Analyst," examined the logic of Newton's "fluxions" and concluded, "They are neither finite quantities, nor quantities infinitely small, nor yet nothing. May we not call them the ghosts of departed quantities. . . ?"

Mathematicians of the 19th Century were to satisfy such critics by invoking new standards of rigor for calculus. But meanwhile it met the test of success—it worked. Scientific problems capitulated to it as the walls of Jericho to Joshua's trumpets. Indeed the chief danger was one of self-satisfaction. Using calculus, scientists explained every process in nature as a sequence of actions and reactions, of causes and effects. Nature, however, cannot be determined in this easy mechanical way. Anyone knows that there are slips between cup and lip—accidents in the forces which produce motion. But the laws of these accidents are also mathematical. And, as we shall see, mathematicians contemporaneous with Newton and Leibniz were working them out as the laws of chance.

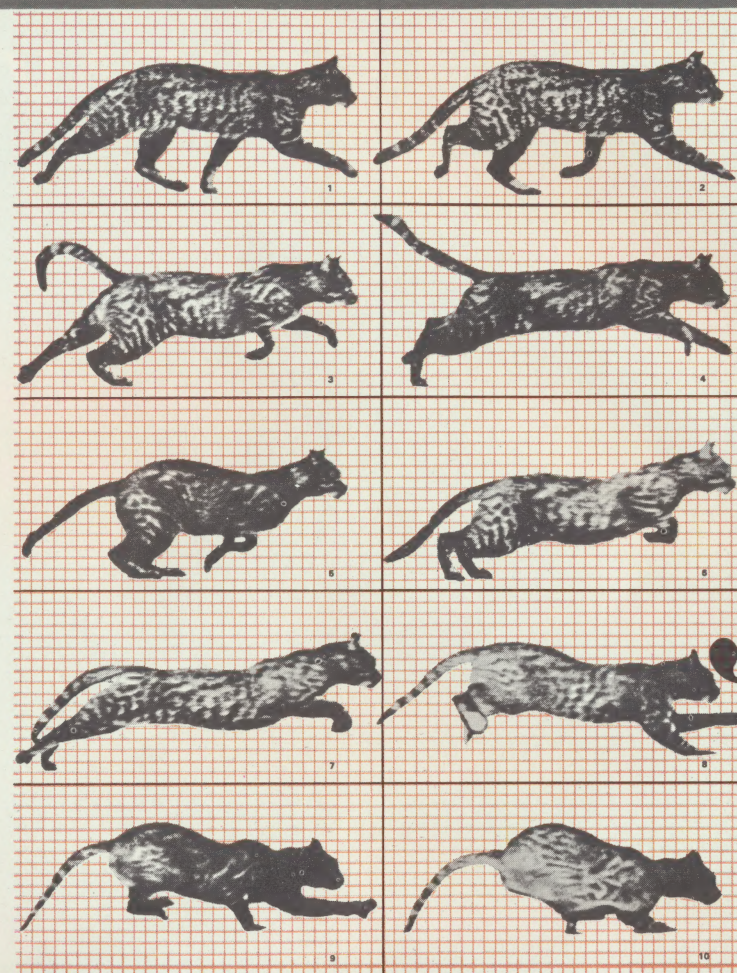
### Calculus: A Way of Probing the Changing World

When the great 17th Century mathematicians Isaac Newton and Gottfried Wilhelm von Leibniz developed calculus as a way of measuring motion, they were, in a sense, introducing to mathematics the principle of the motion picture. For just as a movie film consists of repeated still pictures of a moving object (as in the panels opposite), so does calculus break motion down into "stills" that can be observed "frame by frame." Once calculus was invented, mathematicians could treat a moving object as a point tracing a path through space and, by "stopping the action," calculate the object's speed and acceleration at a specific instant. This mathematics of motion became a fundamental scientific tool. The earth we stand on is in motion; so are the molecules of the air we breathe. With calculus such movements can be defined even though they cannot be seen. Although some of its abstractions are as difficult as anything in mathematics, calculus is based on a few simple ideas—function, approximation, rate of change, convergence, integration—which are explained on the following pages

#### "STOPPING" THE FLIGHT OF A CAT

The famous sequence of photographs on the opposite page, showing a startled cat breaking into a run, was taken in 1887 by Eadweard Muybridge, inventor of a prototype motion-picture

machine. These split-second pictures show that a continuous motion can be broken into small increments of change. In a similar way, calculus treats motion as an infinite number of "instants."



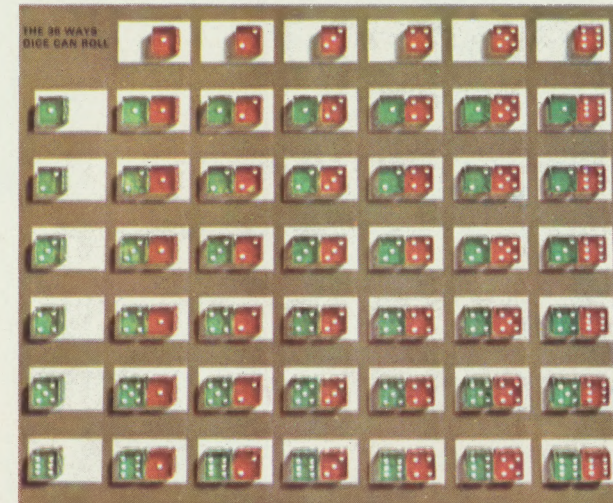
**CHAPTER V** Can a curve be analyzed as a series of infinitely small straight lines that are constantly changing direction? Yes, said German philosopher-mathematician Gottfried Wilhelm Leibniz and English scientist Isaac Newton. Independently of each other they invented the calculus that proved it. In this chapter you meet these men and see how they developed calculus as a kind of mathematical movie camera that enables scientists to study the vast world that is in motion—things that rise and fall, speed up and slow down, increase and decrease—everything from cannon balls and planets to prices. A brilliant LIFE picture essay demonstrates how business and industry depend on calculus to chart their futures, how the entire path of a jet plane's flight, a leaping cat or a man in space can be mathematically determined by the calculus.





### An Immutable Law That No One Can Count On

The theory of probability deals only with the general—never the specific. For example, probability gives the young lady opposite one chance in 36 of winning on any given roulette number—but it makes no guarantee. She may win 10 times in a row; she may play 100 times and never win. Besides refusing to be specific, probability is oblivious to setbacks. The arrangement of the dice below, a graphic display of what is possible with a single toss of two dice, shows that the chances of throwing “snake eyes” (double 1) are 1 in 36. But if a player should get snake eyes 100 times in a row, that would not lessen by one iota the 1 in 36 probability that his 101st turn will come up as a double 1. In this regard, probability has been likened to a kind of faith—unprovable on the one hand, immutable on the other.

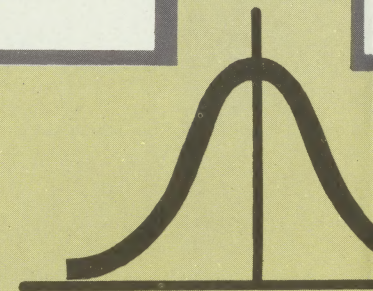


#### WEIGHING THE CUBES' ROLL

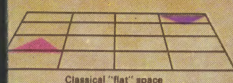
The paired dice above show all 36 possible combinations of a red die (top row) with a green die (left). All arrangements to get a roll of 7 are shown diagonally, from lower left to upper right. Note that while there are only three possible number combinations that make 7 (6 and 1, 5 and 2, 4 and 3), there are six actual combinations of individual dice—a green 6 with a red 1, a red 6 with a green 1, and so on.

**PLAYING A WHEEL'S ANGLES**  
A blond player lays her bet on the spin of a Las Vegas roulette wheel. Probability says she will lose—not necessarily on this turn, but in the long run. The house gives odds of 35 to 1. But actually there are 38 slots the ball may drop into (36 numbers, plus 0 and 00, visible at the far end of the board). In this way the house gains a theoretically unbeatable advantage in long-haul probability of 5% per cent.

**CHAPTER VI** You've flipped a quarter into the air 10 times and each time it came up heads. What are the chances it will be heads the next time? A similar question once asked by a gambler of a mathematician led to the study of Pascal's triangle, an elegant summary of gambling odds that formed the basis for a new type of mathematics, the laws of probability. Here you learn what your chances are to win in face of the odds, how insurance moved from a gamble to a business (why doesn't Lloyd's of London lose money?), how statistics predicts what the many will do by asking the few. You see how understanding games of chance gives businessmen the key to maintaining quality control in the factory, meteorologists a look ahead at next month's weather, physicists the ability to predict chain reactions.







Classical "flat" space

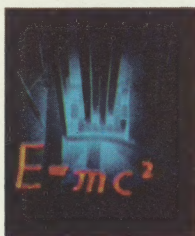


A representation of curved space



Curved space applied to the cosmos

**THE COSMIC SPACE OF EINSTEIN**  
A celestial body such as a star (yellow ball) can be viewed as the center of a section of Riemann's curved space. According to Relativity, the star's mass creates the curvature, and it is this warpage of space rather than the pull of a body on others that causes the effects of gravity.



**GETTING ENERGY FROM MATTER**  
The purple glow of the atomic reactor above and the H-bomb's fireball at right are the fruits of a Relativity equation. This equation,  $E = mc^2$ , states that matter and energy are equivalent. One can obtain energy ( $E$ ) equal to the quantity of the matter ( $m$ ) multiplied by the square of the fantastic speed of light ( $c$ ): 186,000 miles per second. Theoretically, one pound of any kind of matter contains enough energy to propel the largest ocean liner on two Atlantic crossings.

## Explosive Proof of Einstein's Mathematics

The power of mathematics has rarely been shown more effectively than through Relativity. Though mathematicians long ago accepted abstractions such as infinities or square roots of negative numbers, Relativity seemed to run counter to everyday experience. Yet it pulled all the observed facts so neatly together that the scientists were intrigued.

As more and more evidence came in, the scientists' intrigue turned to conviction of Relativity's rightness. Using equations based on his ideas, Einstein was able to make certain predictions about the world. Although these also seemed contrary to

common sense, scientists were soon verifying them with amazing consistency. Light rays appear to bend as Einstein predicted; orbits of planets have strange quirks that classical physics cannot account for, but that Relativity explains; time, length and weight appear to grow or shrink when bodies move at great velocities, just as Einstein theorized.

For the layman, the most unforgettable demonstration was one that confirmed the accuracy of a Relativity equation indicating matter and energy are forms of the same thing. The awesome evidence came with explosions like the one below.

## OUR DENTED SOLAR SYSTEM

A clay model shows how the sun (yellow) and the surrounding planets all create their own curved pockets in space, according to Einstein's theory. Einstein predicted that because of this warping, light rays passing near heavenly bodies would be bent—and scientists have verified this deflection. Much the same thing happens to a spaceship: its path wobbles through the "depressions" of the cosmos, just as if it were a golf ball rolling across an undulating green.



## CHAPTER VII

The political revolution that swept Europe in the 19th Century had its counterpart in mathematics. Carl Friedrich Gauss, greatest mathematician and astronomer of his time, and his student, Bernhard Riemann, modernized Euclidean geometry with unconventional concepts of mathematical curved spaces where the shortest distance between two points is a curved line, concepts applied by Einstein to give a new view of our universe. These men, and others, formed the basis for today's nuclear physics. MATHEMATICS shows you how they did it and what it means to our lives today. You learn the structure of modern mathematical ideas. Concepts you may have felt formidable become clear when you see how they apply in countless ways to your immediate world.